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Satellite CD Radio

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

November 23, 1994

Federal Communications Commission
2025 M Street, NW
Room 7102
Washington, DC 20554

Attn: H. Franklin Wright, Chief
Frequency Liaison Branch

re: Satellite CD Radio Experimental License, Call Sign K02XES

Dear Mr. Wright:

Satellite CD Radio, Inc. ("CD Radio") hereby files its experimental report for tests conducted under the above-captioned license.

If any questions arise concerning this report, please contact the undersigned.

Respectfully submitted,

Robert D. Briskman

Robert D. Briskman
President
Satellite CD Radio, Inc.

cc: FCC File PP-24

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CD RADIO

S-Band Propagation Measurements

Robert D. Briskman
CD Radio Inc., Washington, D.C.

INTRODUCTION

A geosynchronous satellite system capable of providing many channels of Digital Audio Radio Service (DARS) to mobile platforms within the contiguous United States using S-band radio frequencies is being implemented. The system is designed uniquely to mitigate both multipath fading and outages from physical blockage in the transmission path by use of satellite spatial diversity in combination with radio frequency and time diversity. Figure 1 shows the generalized system configuration. The system also employs a satellite orbital geometry wherein all mobile platforms in the contiguous United States have elevation angles greater than 20° to both of the diversity satellites. Since implementation of the satellite system will require three years, an emulation has been performed using terrestrial facilities in order to allow evaluation of DARS capabilities in advance of satellite system operations. The major objective of the emulation was to prove the feasibility of broadcasting from satellites 30 channels of CD quality programming using S-band frequencies to an automobile equipped with a small disk antenna and to obtain quantitative performance data on S-band propagation in a satellite spatial diversity system.

DARS SATELLITE SYSTEM

The satellite system consists of two geosynchronous satellites, one located over the east coast of the United States at 80° West Longitude and the second over the west coast of the United States at 110° West Longitude. The satellites receive in the 6720 MHz band and transmit in two 8 MHz segments of the 2310-2360 MHz band. The satellites each receive the same transmission from the system's up-link/programming center essentially simultaneously and retransmit the signal through an antenna beam covering the contiguous United States. Figure 2 shows the block diagram of the satellite's transmission payload. The retransmission frequencies of the two satellites are separated by 20 MHz and the beam edge EIRP is 57 dBW. The high EIRP is required due to the low gain of the mobile platform antenna. The transmission consists of 30 stereo CD music channels, a 128 kb/s service channel and several information channels. The CD stereo music channels are compressed prior to transmission using a joint encoding algorithm based on perceptual audio coding so only a 128 kb/s output data rate is required for each. The channels are digitally multiplexed together (i.e., TDM-time division multiplex) with interleaving in time, resulting in a 4 Mb/s output signal.

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The output signal is convolutionally encoded, a Reed-Solomon code added and then transmitted to the satellites using offset quadraphase shift keying.

The satellite retransmissions are received by the mobile platforms, particularly passenger automobiles. The mobile platform G/T at worst operational aspect angle is -19 dB/K. The antenna is designed to provide 3 dBi gain within a 20°-60° elevation angle range at all azimuths. The antenna is physically 2.5 cm in radius and 0.4 cm thick, designed for embedment in automobile rooftops. A photograph of the antenna is shown in Figure 3. After radio frequency reception, amplification and down conversion, the transmission from each satellite is individually demodulated. The two signals are time phased together using a maximal ratio combiner and then de-multiplexed. The user selects the specific music channel desired which is then routed to the decompressor, the digital-to-analog converter and the audio amplifier-loud speaker subsystem. Figure 4 shows a block diagram of the mobile platform receiver. The mobile platform receiver just described enjoys great resistance to multipath fading and outage from blockage since its mechanization takes advantage of satellite spatial, frequency and time diversity as depicted in Figure 5.

EMULATION IMPLEMENTATION

It is difficult to emulate the capabilities of the previously described DARS satellite system using terrestrial facilities to simulate the satellites. This is because achieving a 20° elevation angle to the mobile platform from a terrestrial transmitter simulating the satellite over a reasonably large area requires buildings or towers of great height. Also, the demonstration of spatial diversity requires two transmitters covering the same geographical area resulting in the need for several transmitters. A satellite system emulation range was constructed in Northern Virginia close to Washington D.C. Figure 6 is a roadmap of the range. Five high-rise building tops were used as transmit locations to a vehicle driving a route through the area configured so that two transmit locations are nominally at 10° or more elevation angle from the vehicle, and only one transmit path at a time experiences physical blockage. The particular driving route included areas representing both urban and suburban environments as well as areas with trees and a roadway overpass.

The 30 CD music channels and service channel were generated at a programming/up-link earth station in Washington, D.C. using the compression, multiplexing and modulation described earlier. The uplink station transmitted the signal at Ku-band to the SBS-6 satellite which relayed the signal to standard VSATs on the high-rise building roofs. The VSAT received signal was translated by a stable frequency converter to the 2310-2360 MHz band and was then re-radiated using a small S-band transmitter and omni-directional antenna. The S-band EIRP of the transmitters was adjusted to provide a signal strength equal to that which would have been received at the mobile platforms from the previously described geosynchronous satellites throughout the nominal vehicle route. The standard passenger vehicle used for the emulation was outfitted with a prototype receiver electronically almost identical to those that would be used in the operational satellite system. A small depression was made in the car roof, the antenna inserted and the roof area repainted to make the antenna invisible. The automobile radio was modified with a single button to select Satellite Radio in addition to AM and FM, and an expanded display was used to show the driver the music composition name and composer being played on the CD channel selected. A photograph of the display is shown in Figure 7.

EMULATION OPERATIONS

An application was submitted to the FCC in December 1992 for an Experimental License to conduct the previously described emulation using rooftop mounted transmitters in the 2310-2360 MHz radio frequency band. The license was granted on February 25, 1993 and the measurements subsequently cited were performed primarily from April 1993 through early June 1994.

A simplified block diagram of the system used for the emulation is shown in Figure 8. Note that the automobile used a four channel receiver, rather than the two to be used in the actual DARS satellite system, to avoid self interference from the relatively closely spaced rooftop antennas and that the 30 music channels were compressed individually and then multiplexed. Twenty minute music segments were then placed on the computer disk at the up-link earth station for transmission during the demonstration. The music segments would repeat automatically at the end of the twenty minutes.

PROPAGATION DATA

Accumulation of propagation data is performed when satellite transmission time is available and when the emulation automobile is not used for demonstrations of service capability. Data on transmission performance are logged on a monitoring UNIX based computer in the automobile trunk and then transferred to a large office computer at headquarters. Essentially received transmission data are logged four times per second as a record containing time, location, signal strength and bit error rate. Data reduction may be performed as a function of either time period or car wheel rotations.

The results to date fall into three categories:

1. **Blockage** Considerable data were taken on blockage avoidance by satellite spatial diversity, especially overpasses. Some selected measurements of interest are presented. Figures 9, 10, 11 show that no blockage occurred at measuring points around the driving range. At least one receiver channel always had a signal above threshold. A special test of blockage avoidance was made on one of the largest freeway

overpasses in the Washington, DC area, and the measurements are summarized in Figure 12. The measurements show that no blockage outage would occur in vehicles passing under the overpass with the diversity satellite DARS system for the geometry utilized but would always occur for a single satellite DARS system.

2. **Multipath** The nominal margin over threshold in the DARS satellite system for each received transmission without diversity combining is 5dB. This required operation of the test range at increased transmitter power for statistical measurement of multipath fading up to 20dB. The data acquired to date indicate that greater than 12dB improvement was almost always obtained from diversity but the statistical distribution above 12dB awaits further data taking.

3. **Frequency Selective Fading** There was observed, on occasion, unanticipated high levels of frequency selective fading. Figure 13 shows two examples of such fades; the left hand plot containing a narrowband (0.5MHz) fade of 15dB in the lower frequency transmission and the right hand plot containing a wideband (4MHz) fade of 20dB in the upper frequency transmission. In both cases, the satellite frequency diversity scheme would have prevented a service outage.

SUMMARY

The propagation data obtained to date at S-band demonstrate the effectiveness of satellite spatial diversity in mitigating DARS service outages from blockage and multipath. Further data will be accumulated for determining accurate multipath improvement performance statistics.

Figure 1 -- The CD Radio System

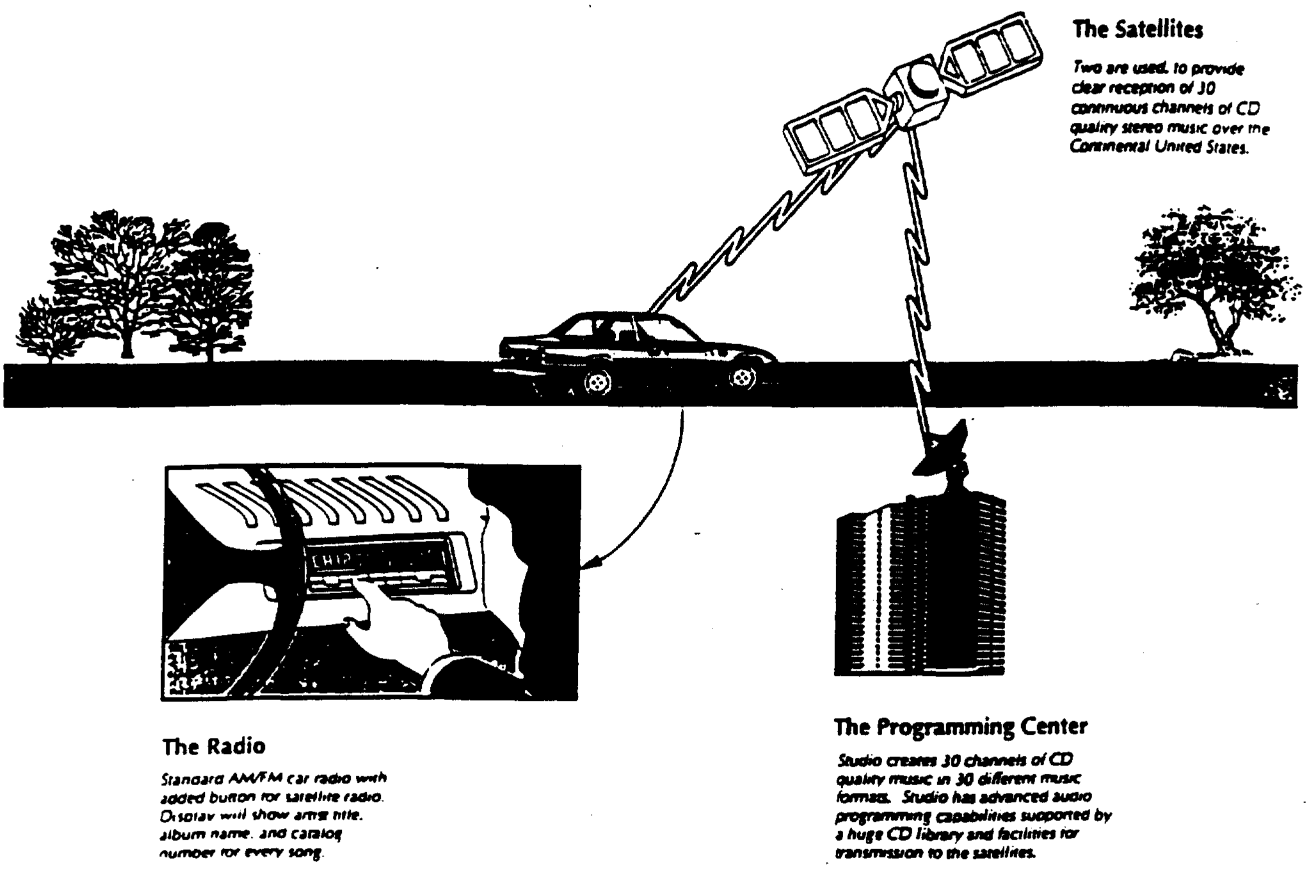

Figure 2 -- CD Radio Satellite Communications Block Diagram

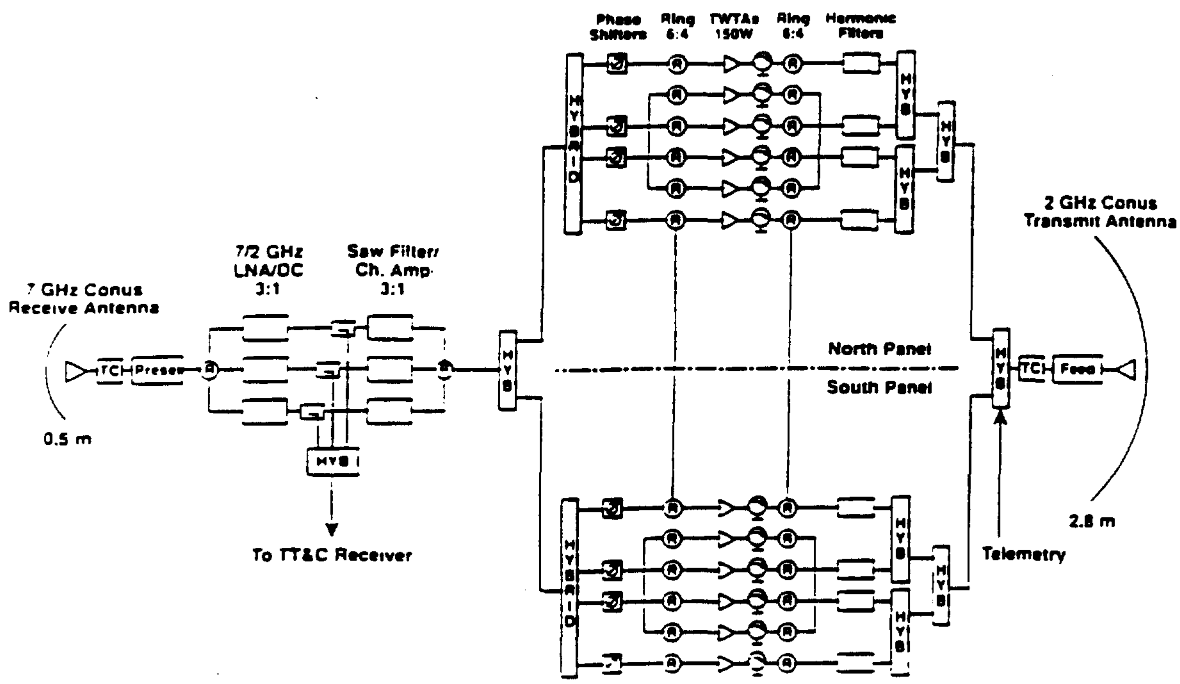

Figure 3 -- CD Radio Antenna

Figure 4 -- Vehicle Receiver
Analog AM & FM / Digital Satellite & Terrestrial

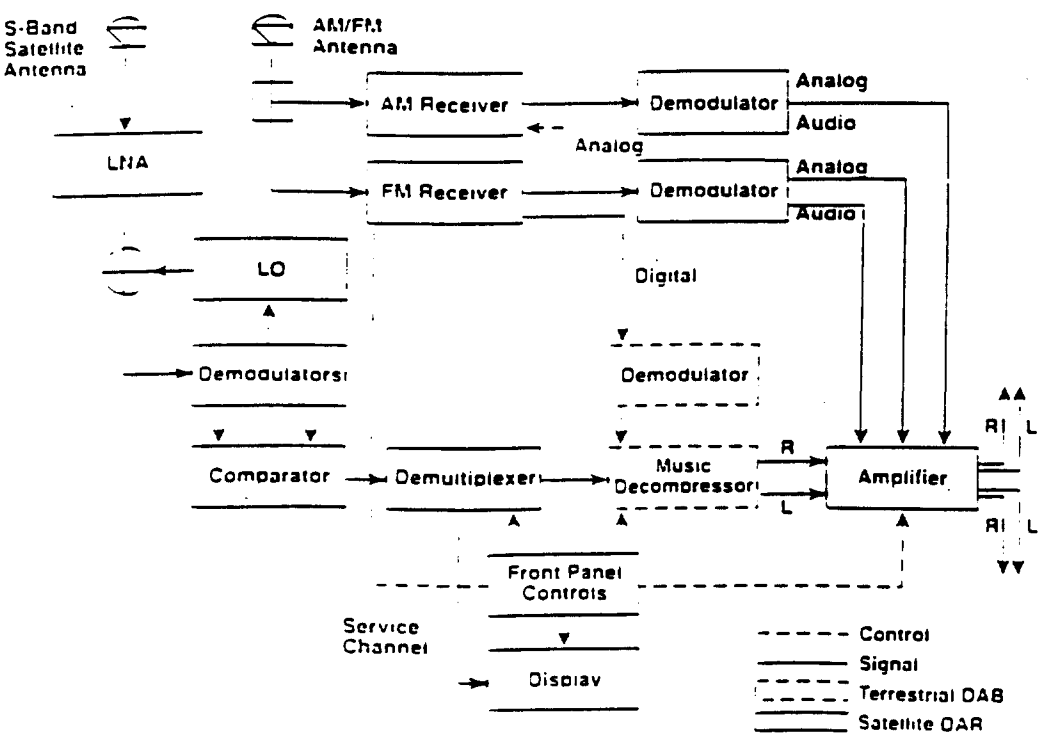

Figure 5 -- Reduction of Blockage Outages*
By Use of Two Radio Broadcast Satellites

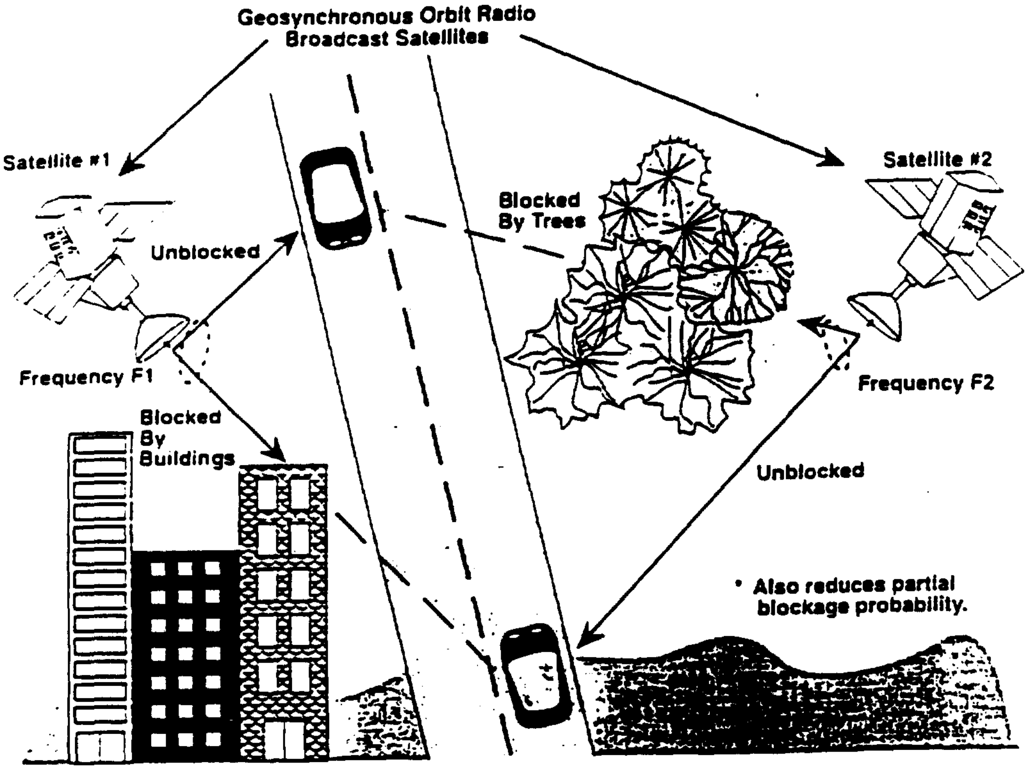

Figure 6 -- Test Range Road Map

*Note: The test range is in Arlington, Virginia, part of metropolitan Washington, D.C.

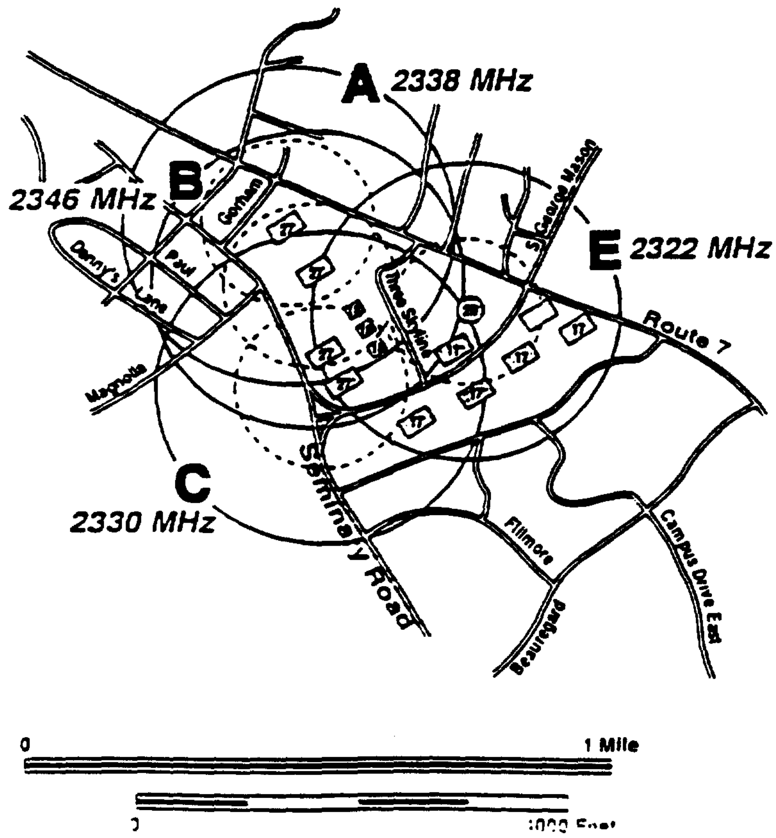

Figure 7 -- Car Radio Display

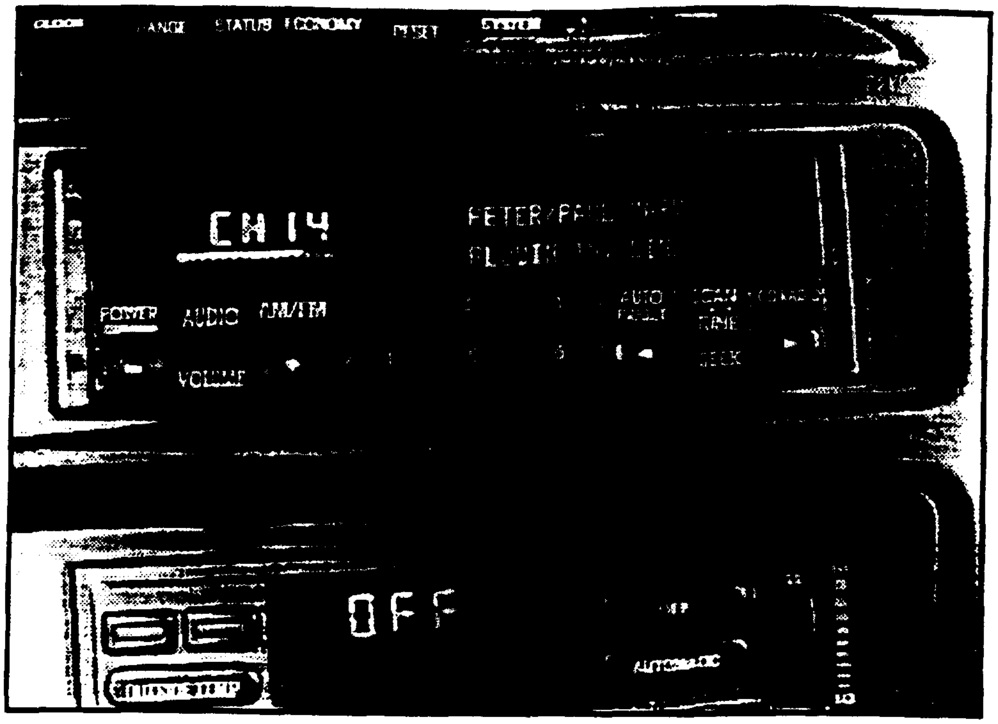

Figure 8 -- CD Radio Test System - Block Diagram

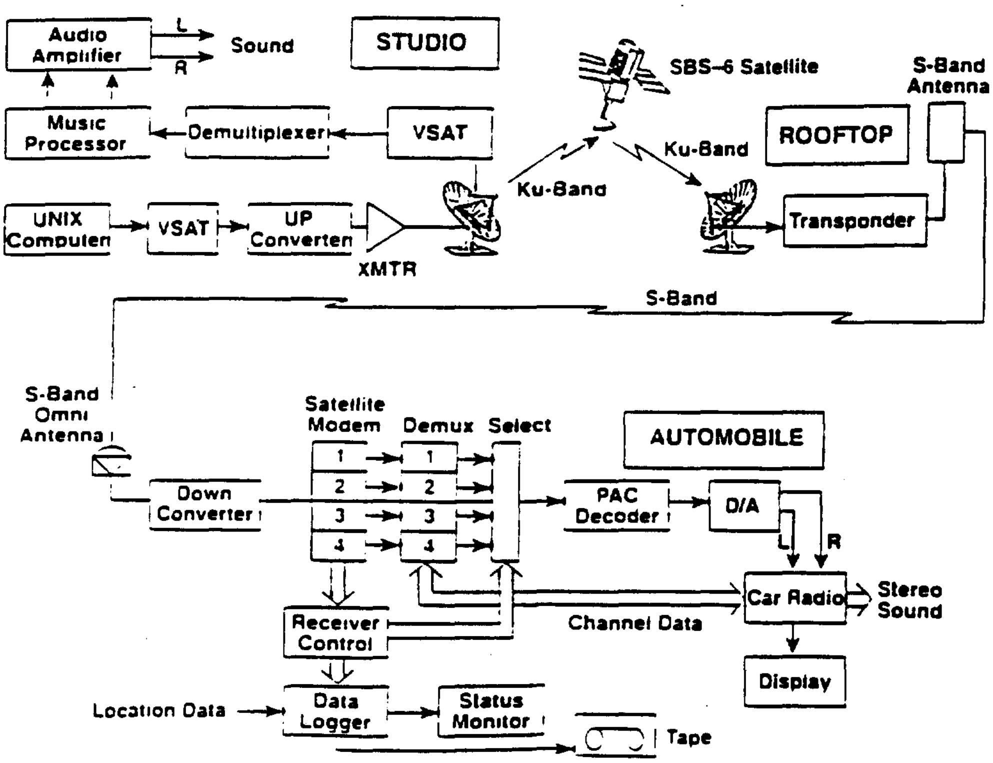

Figure 9 -- Test Range Measurement Points

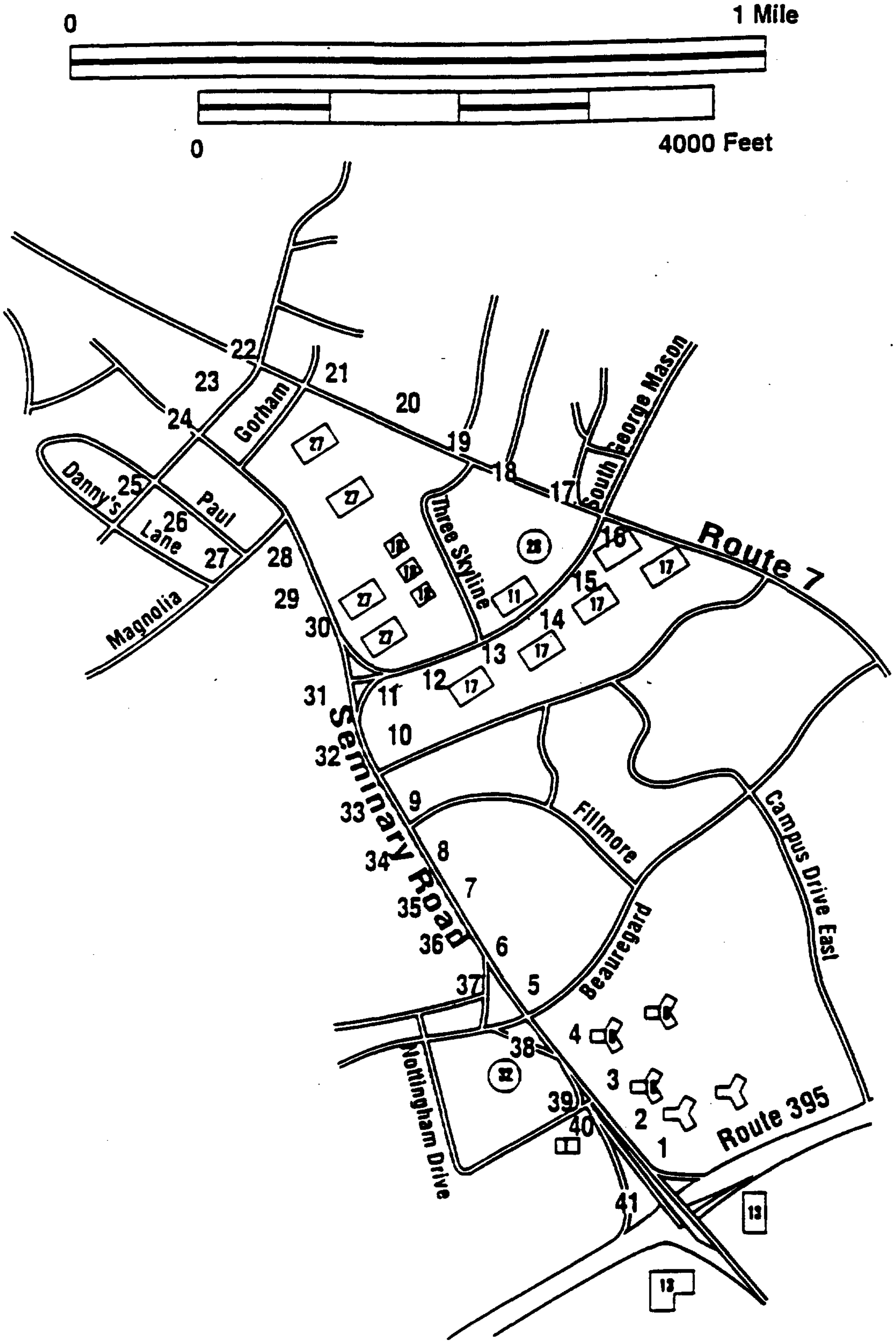

Figure 10 -- Test Range AGC Measurements - Sheet 1 of 2

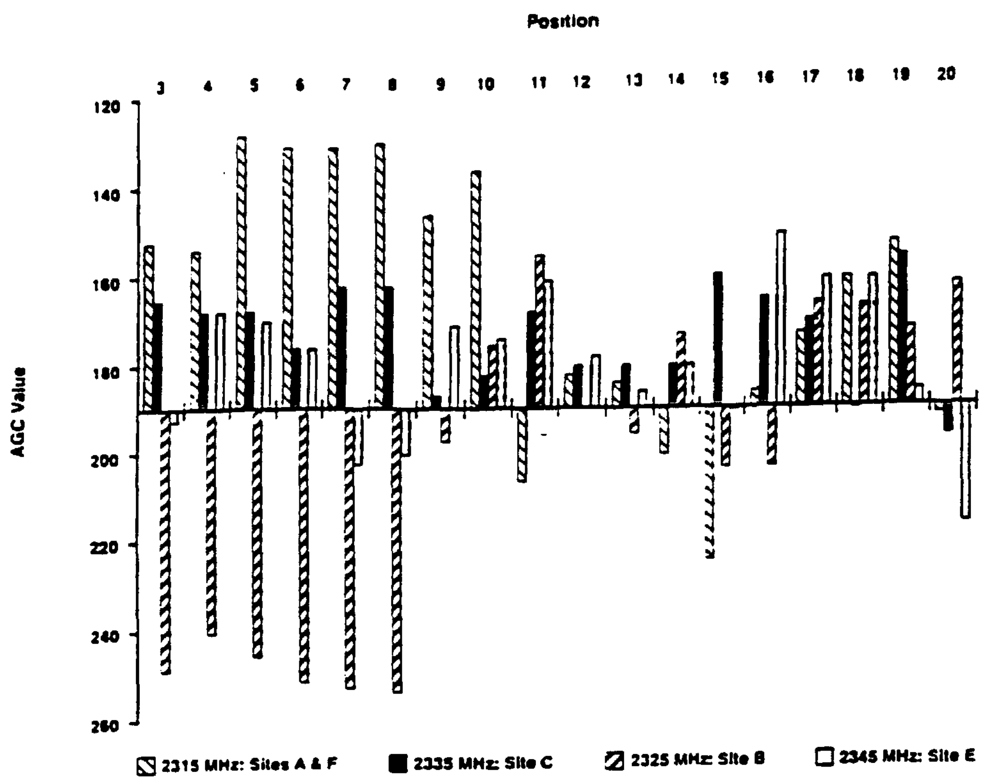

Figure 11 -- Test Range AGC Measurements - Sheet 2 of 2

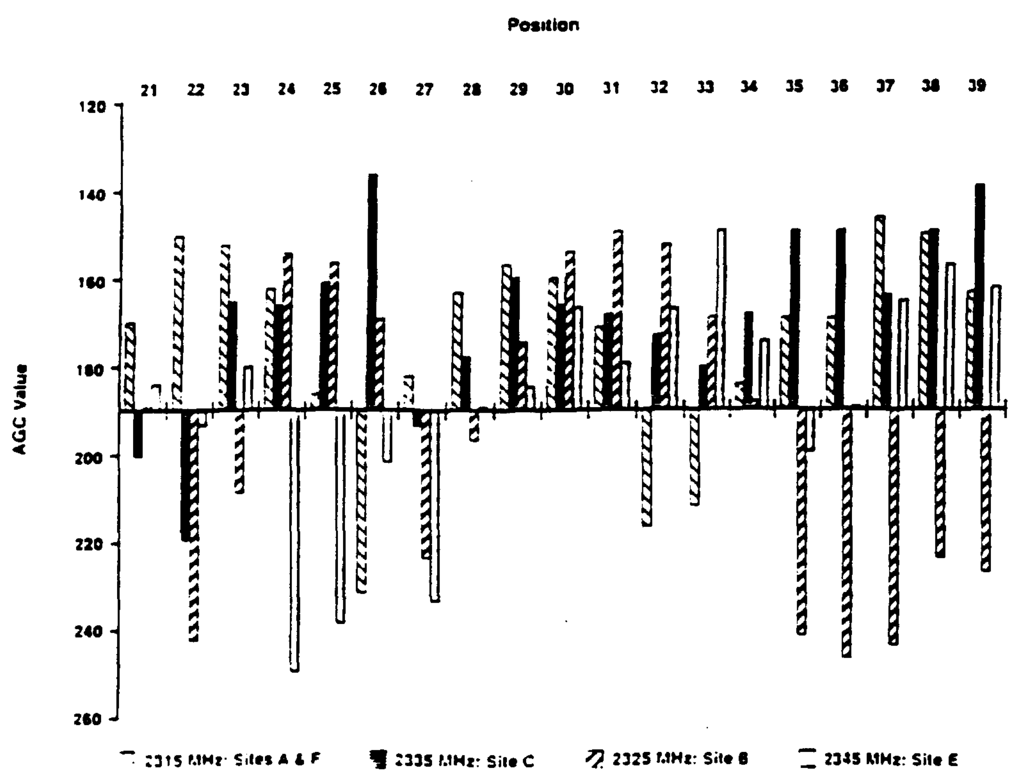

Figure 12– Highway Overpass, Test Results Summary

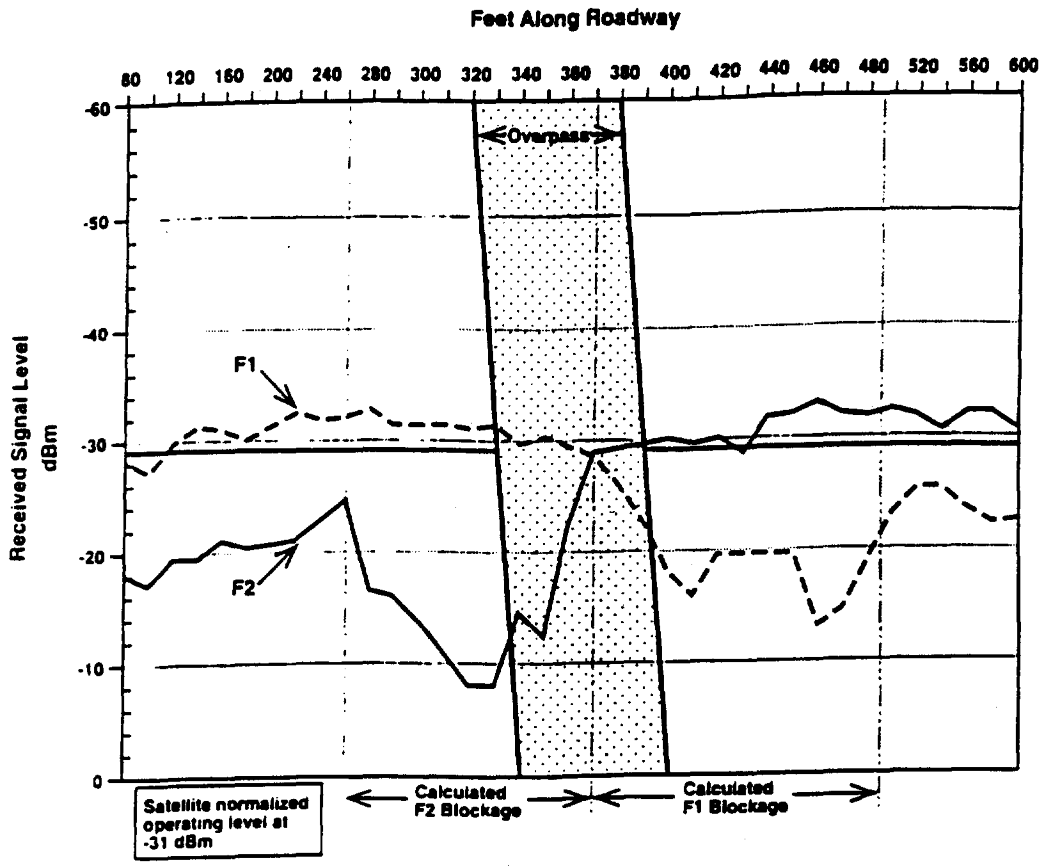

Figure 13– Test Range Spectrum Plots